Modelling land cover change impact on the summer climate of the Marmara Region, Turkey

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Abstract: Landscape characteristics of the Marmara Region, Turkey, changed significantly after the 1980s as a result of rapid industrialisation and population increase. To investigate the effects of these land cover changes on the summer regional climate, we implemented 1975 and 2005 land cover maps of the region produced from Landsat images into the Weather Research and Forecasting (WRF) regional climate model. Urbanisation and conversion from forest to barren areas increased average temperatures by 0.5–1.5°C. Significant precipitation changes could not be detected. The average wind magnitude decreased by 0.3–0.9 m/s over the city and surrounding areas.

Keywords: land cover change; regional climate modelling; urbanisation; land surface–climate interactions.

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1 Introduction

The climate system includes the land surface, atmosphere, oceans and other water bodies, the cryosphere and the biosphere. The interactions between the components of the system are complex, and accurate representation of each component and its interactions is very important for the accurate simulation of the climate. Currently, global and regional scale numerical models have been used to simulate the climate system and the physical interactions among the system's components. The climate over the land surface is extremely important to us since it is where we live. Partitioning of available energy at the surface between sensible and latent heat and partitioning of available water between evaporation and runoff are controlled by the land surface. Land has a heterogeneous structure since it includes different land cover types such as bare soil, water and urban varying on different scales. This surface variability has impacts on both microclimate and mesoscale atmospheric circulation (Hartmann, 1994; Weaver and Avissar, 2001; Yang, 2004).

Human beings, like other living organisms, have always influenced their environment. The impact of human activities has begun to extend to a much larger scale, continental or even global since the beginning of the Industrial Revolution in the mid-18th century. As a result of human activities, in particular those involving the combustion of fossil fuels for industrial or domestic usage and biomass burning, the composition of the atmosphere has been affected. The emission of chlorofluorocarbons (CFCs) and other chlorine and bromine compounds has impact on both the radiative forcing and the depletion of the stratospheric ozone layer (IPCC, 2001).

Physical and biological properties of the Earth's surface have been affected as a result of land-use change, due to urbanisation and human forestry and agricultural practices. Such effects change the radiative forcing and have a potential impact on regional and global climate (IPCC, 2001). Human activities have considerably altered Earth's surface, especially during the last several hundred years (Vitousek et al., 1997). Local, regional and global climate can be affected by such disturbance because of the change of the energy balance on the Earth's surface and the chemical composition of the atmosphere (Pielke et al., 2007; Pielke, 2001).

Accurate representation of the land surface is important to precisely model the impact of land cover change on climate. Previously, we used Landsat Enhanced Thematic Mapper Plus (ETM+) images to create accurate and up-to-date land cover data for regional climate modelling (Sertel et al., 2010). We analysed the quality of Global Land Cover Characteristics (GLCC) data used in the regional climate models by comparing these data with 2005 Landsat ETM+ derived land cover data. We found errors in GLCC data because of them not being up-to-date and because of misclassification. We investigated the impact of land cover data quality on numerical modelling simulations by conducting two numerical simulations, one with Landsat-derived land cover and one with GLCC data (Sertel et al., 2010). We found that simulation results with the Landsat-derived land cover data set produced more accurate temperature simulations for the region. In this study, we produced 1975 land cover of the region using Landsat Multispectral Scanner (MSS) images in addition to 2005 land cover data. We conducted another numerical simulation with 1975 land cover data and addressed the following scientific questions:

- How did land cover change in the Marmara Region between 1975 and 2005?
- How have these changes affected the summer climate of the region?

2 Study area and data

The Marmara Region, which experienced significant land cover changes as a result of rapid industrialisation and population increase especially after 1980s, was selected as the study area. The Marmara Region is located in the northwest of Turkey, between latitudes 29°N and 32°N and longitudes 38°E and 42°E and covers an area of 67,000 km^2.

Turkey is in a region that is often described as having a warm and moderate climate (Erinç, 1996). Its diverse regions have different climates, with the weather system on the coasts contrasting with those prevailing in the interior. The climate is moderate in the Marmara Region (winter 5°C and summer 25°C); in winter, the temperature may drop below 0°C.

Landsat MSS obtained between 1972 and 1975 and Landsat ETM images obtained between 2001 and 2005 were used to create land cover maps of the study region. The study region includes six Landsat frames. Landsat MSS sensor images have four spectral bands with 80 m spatial resolution, whereas Landsat ETM sensor images have seven spectral bands with 30 m spatial resolution. In addition to Landsat MSS and ETM sensor images, Landsat TM, SPOT and IKONOS images available in the Istanbul Technical University Remote Sensing Laboratory were used to assist classification and geometric correction procedure. Meteorological station data including daily temperature (min, max and average), daily average wind and daily total precipitation were obtained from the State Meteorological Office of Turkey.

National Centers for Environmental Predictions (NCEP)/Department of Energy (DOE) Reanalysis II data (R-2, Kanamitsu et al., 2002) were used as initial and boundary conditions for the numerical experiments. R-2 is an updated and improved version of the NCEP/National Center for Atmospheric Research (NCAR) reanalysis project (N/N, Kalnay et al., 1996), since in R-2, global analyses were made using an updated forecast model, updated data assimilation system and improved diagnostic outputs and fixes for the known processing problems of N/N.

We used the WRF (Skamarock et al., 2005) modelling system to conduct numerical simulations to analyse the impact of land cover change on regional climate of the region. Ground photographs, Digital Elevation Models, field samples, 1/25,000 scaled topographic maps and forest maps were also used in this study. Most of the maps, photographs and field samples were used to select training sites and perform accuracy assessment for the classification.

3 Methodology

Digital numbers of all images were first converted into radiance and then to at-satellite reflectance values. Gain and offset parameters provided by NASA were used to calculate radiance values of each band of all images.

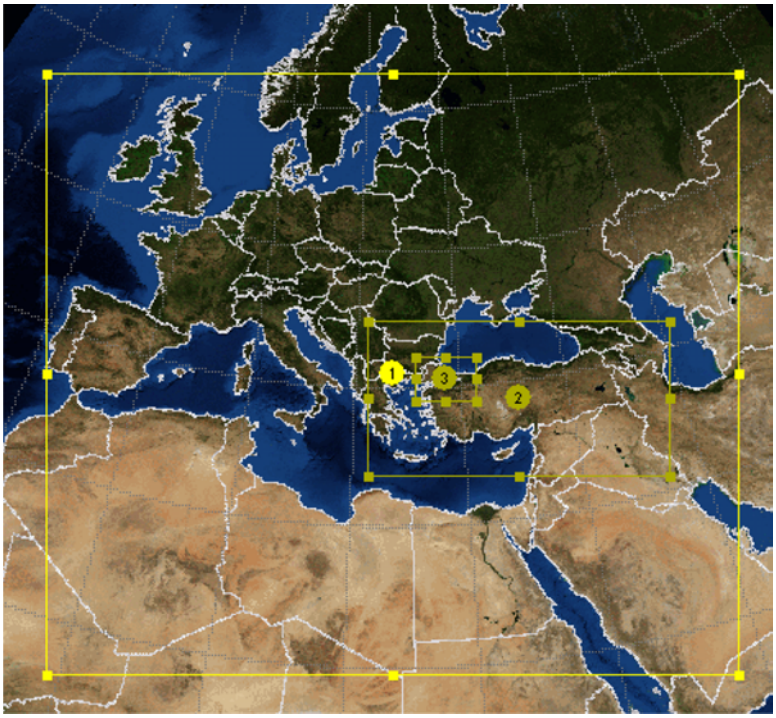
Atmospheric correction of the satellite images was performed using the dark object subtraction method to minimise contamination effects of atmospheric particles. Lakes, seas or other water bodies, which have very small reflectance, were selected as dark objects. The minimum reflectance values of these objects were assumed as the effect of the atmosphere.

Geometric correction was performed for each image to eliminate geometric distortions, correct errors in the relative positions of pixels and define images in a common coordinate system. Geometric correction was applied using affine transformation and ground control points derived from topographic maps, which were homogenously distributed over images. Each image was transformed into latitude and longitude coordinate system with the WGS 84 Datum.

Both supervised classification using the Maximum Likelihood technique and unsupervised classification using ISODATA clustering were conducted to classify images. Classified images were aggregated to 1 km, since numerical simulations do not require very high resolution and match land cover data resolution with other data sets and nested domain. Error matrix analysis was conducted to analyse the accuracy of classifications.

These land cover data were then implemented into WRF to quantify the land cover change impact on the summer climate of the research area. The experiments were conducted for the summer (June–August) season. One main and two nested domains were formed with 27 km, 9 km and 3 km horizontal resolution, where the 3 km domain represented the study area (Figure 1). To analyse the general circulation of the atmosphere, the main domain covered 25°N to 60°N latitude and 15°W to 55°E longitude and had 180×142 grid points. Numerical simulation results obtained from using the 1975 and the 2005 land cover data were compared, and the land cover change impact on summer climate of the Marmara Region was examined.

Figure 1 Boundaries of research domains used to run WRF (see online version for colours)



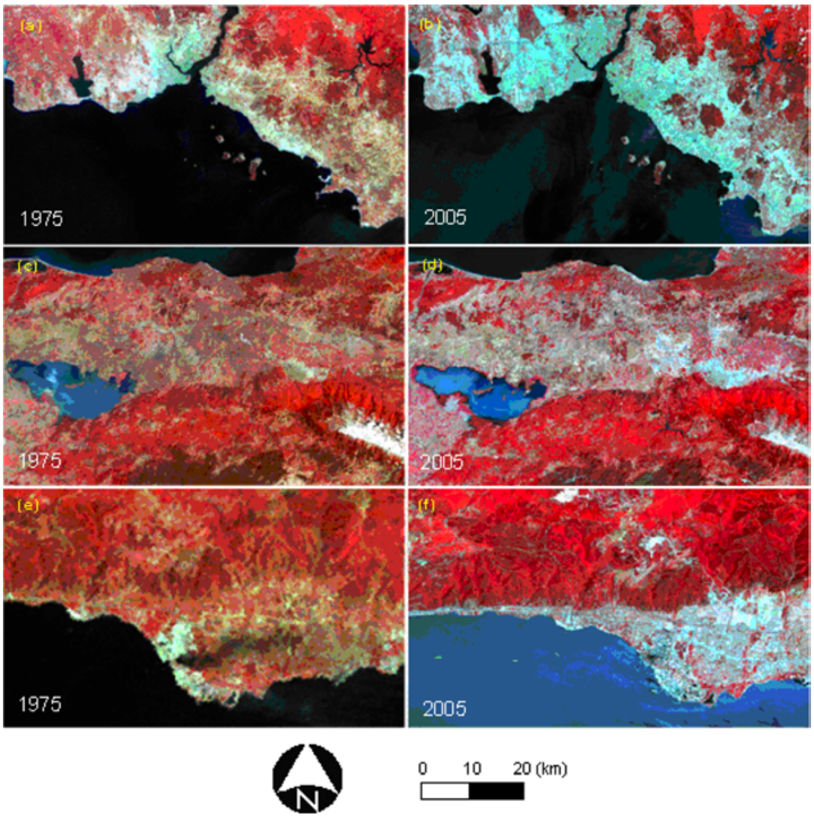
4 Results

4.1 Land cover change

Land cover changes occurred in Marmara Region both in coastal and in inland areas as a result of human activities. Metropolitan cities in the region, like Istanbul, Adapazari and Bursa, grew by industrialisation and immigration, which resulted in increases in the urban and built-up areas (Figure 2). Besides, in Istanbul, forest areas and sand dunes were destroyed by open mining activities performed in on the Black Sea coast of the European part. As a result of dumping materials extracted from open mining areas into the sea, the ecosystem and topographic structure were damaged (Kaya et al., 2008). In this region, natural land cover changes also occurred as a result of coastal erosion. There were three significant land cover changes in Marmara between 1975 and 2005. First, as a result of urbanisation, total urban areas increased from 25,659.3 ha in 1975 to 104,966 ha in 2005. Second, there was a decrease in total crop area from 4,480,105 ha in 1975 to 4,364,569 ha in 2005. 45906.1 ha of crop area was converted into urban area during this period. The third change was deforestation; there were 4,123,348 ha of forest area in 1975 and 4,090,827 ha in 2005.

The 1975 and 2005 land cover data produced from Landsat images were implemented into WRF and two separate numerical experiments were conducted. Simulation results obtained from 1975 and 2005 land cover data were compared, and the land cover change impact on the summer climate of the Marmara Region was examined.

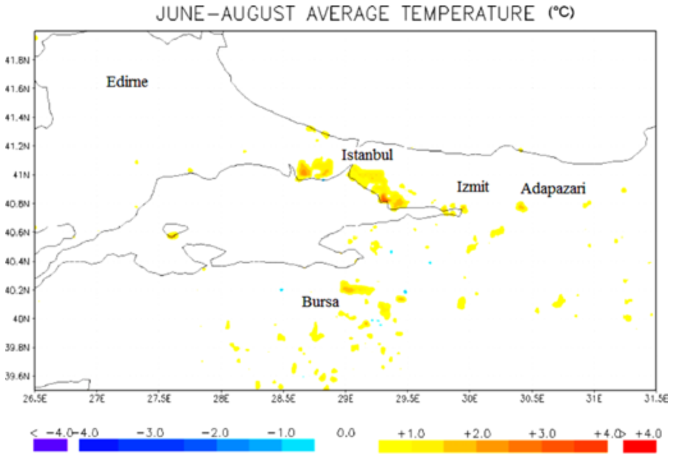
Figure 2 Urban sprawl in Istanbul (a, b); Bursa (c, d) and Izmit (e, f). Band Combinations 3,2,1 were used for 1975 Landsat MSS and 4,3,2 for 2005 Landsat ETM+. In both cases, the greyish green areas are the cities (see online version for colours)



4.2 Numerical simulations

Heat islands develop when a large fraction of the natural land cover in an area is replaced by built surfaces that warm faster during the daytime because they are drier with less vegetation and evaporate less, producing less latent heat (Quattrochi et al., 2000; Oke, 1982). This also keeps nighttime air temperatures high relative to temperatures in less urbanised areas (Oke, 1982). This increase in urban air temperatures when compared with surrounding suburban and rural temperatures is referred to as the heat island effect. Temperature increase as a result of urbanisation can be seen by comparing average temperatures difference obtained from numerical simulation results conducted with 1975 and 2005 land cover data (Figure 3). Urbanisation in the Anatolian part of Istanbul was bigger than in European part, which resulted in average temperature increase between 0.5°C and 1°C in the European part, between 0.5°C and 1.5°C in the Anatolian part. Average temperature differences over Bursa, Adapazarı and Izmit were between 0.5°C and 1°C. Conversion from forest to barren areas increased average temperatures by 0.5°C in coastline of Istanbul European side (Figure 3). 0.5°C cooling of average temperatures occurred in a small region around Bursa with the conversion of the sparsely vegetated areas into forest areas.

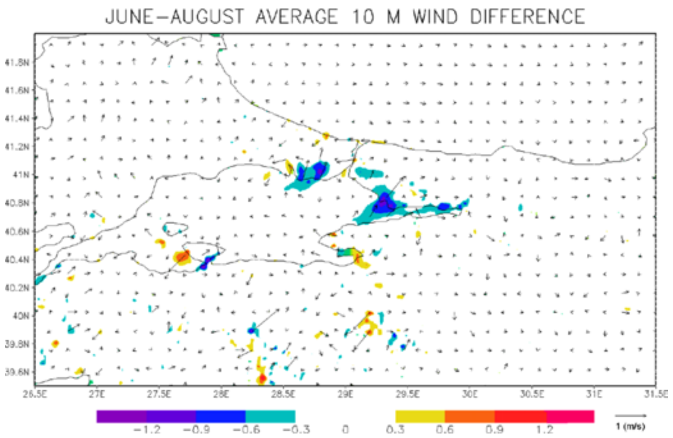
Figure 3 June–August average temperature difference between 2005 and 1975 in WRF model runs (see online version for colours)



In general, precipitation increase was detected over urban areas and over the areas where land cover changed from sparsely vegetated to deciduous forest. Precipitation decrease was detected over the Thrace Region (northwest part of the Marmara Region) with the increase in crop areas. But, the precipitation changes were heterogeneous and not significant.

Figure 4 illustrates the differences of average 10 m wind for June–August period. Bigger differences occurred where land cover changed from crop to urban and sparsely vegetated to deciduous forest. It seems that the urbanisation decreases the wind magnitude over the city and surrounding areas. The wind vectors show a southwesterly anomaly over Istanbul. The changes in wind magnitude and wind vectors show that the velocity of the northeasterly winds reduced over Istanbul. This might be a response to the increased roughness length when the landscape changed from crop to urban. Changes in direction and magnitude of winds are important when air pollution and its transport are considered.

Figure 4 June–August average 10 m wind difference between 2005 and 1975 (m/s) (see online version for colours)



4.3 Statistical significance

In this research, the *t*-test was used with 95% significance and the null hypothesis assumed that the results of 1975 and 2005 simulations are equal. Using the mean, standard deviation and number of data points for each simulation, a *t* test was conducted to determine whether the changes between 1975 and 2005 are significant or not.

The test results illustrated that the warming over the urban areas of Istanbul, Bursa, Adapazari and Izmit is significant. Also, some significant warming trends were found on the coastline of Istanbul because of forest to barren, water to barren and forest to sparsely vegetated conversions. These regions were where the open mining activities were conducted and sea was filled with the residuals of these activities. Significant cooling of average minimum temperature was found for limited areas because of the conversion of sparsely vegetated to forest and grass to forest. Conversion from forest to sparsely vegetated and sparsely vegetated to crop caused significant warming for some small regions.

Although some small precipitation increase and decreases were found over the different parts of the Marmara Region, none of these trends was statistically significant.

5 Conclusions

Introducing multitemporal land cover data in WRF modelling system produced different results emphasising the impact of land cover change impact on climate. There are warming effects because of urbanisation, open mining activities and deforestation and there are cooling effects because of reforestation and increase in water areas. There are also increases and decreases in precipitation patterns and changes in distribution and magnitudes of winds. However, not all these changes in climatic variables are significant and application of the *t*-test helped us to find out significantly changed climatic variables and their locations.

The results of this work are evidence that anthropogenic land cover change has impacted several aspects of the regional climate of the Marmara Region, including warming of 2 m air temperatures and the changes in the strength and orientation of the sea breezes. Urbanisation increase in Istanbul, Bursa and Adapazari resulted in urban heat island effect over these cities. Changes in temperature and wind patterns due to land cover changes depend on the type of land cover conversion. Changes in land cover with further human activities will also impact the future climate of the region. This conclusion has important implications for land-use planning and water and natural resource protection in the Marmara Region.

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